Effective Radius of Cloud Droplets Derived from Ground-Based Remote Sensing at the ARM SGP and NSA sites

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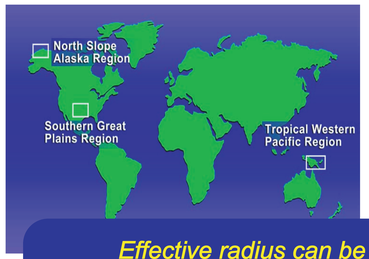
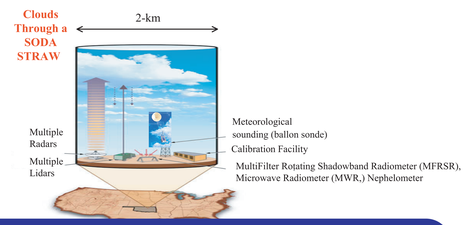
Introduction

- Enhanced cloud drop concentrations may be expected to increase cloud optical depth and reflectivity, reduce absorption of solar radiation, and produce a cooling effect (Twomey, 1977).
- Recently, aerosol enhancement of cloud optical depth and albedo was demonstrated using satellite data and chemical transport model (Schwartz et al., *PNAS*, 2002)
- Surface remote sensing has the advantage of continuous operation over long periods and can examine long-term trends in aerosol properties.
- Here, we examine cloud drop effective radius (r_e) and investigate its relationship to aerosol concentration / meteorological conditions using ARM data for the year 2000.

* U.S. DOE's ARM program
> Conducting continuous and integrated measurements of radiation, cloud and aerosol properties at SGP & NSA sites.

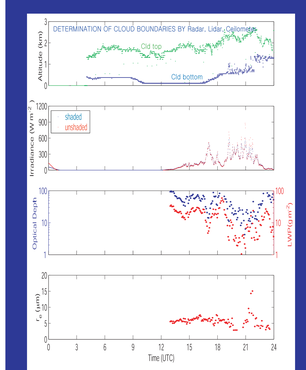
- Cloud optical depth and liquid water path (LWP) are retrieved from remote sensing and r_e is derived from the surface by remote sensing.





Case Selection & Data Retrieval

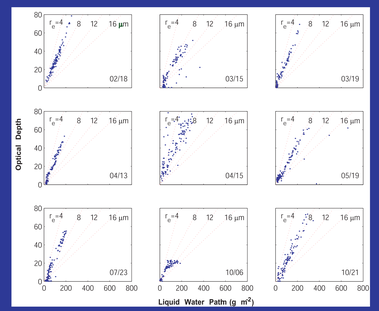
Required Conditions
- Complete overcast needed for the determination of τ by using MultiFilter Rotating Shadowband Radiometer (MFRSR)
- Low level liquid water clouds without overlying cloud
- Clouds in boundary layer to be related to aerosol at the surface.



1. Low-level and thin cloud layer selected and not interfered by higher-level ice clouds
2. Completely overcast cloudy situations screened using shaded and unshaded irradiances measured by pyranometers
3. Cloud optical depth (τ) obtained using the observed atmospheric transmittance, and surface albedo (Min and Harrison, *GRL*, 1996).
4. Cloud liquid water path (LWP) measured by a microwave radiometer (MWR) used to obtain effective radius (r_e) of cloud droplets.

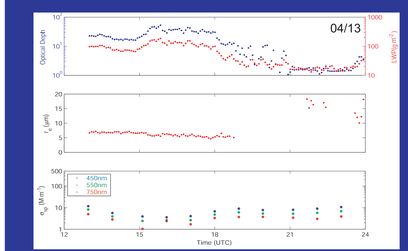
$$LWP = \frac{2}{3}\rho_w \tau_c < r_e >$$

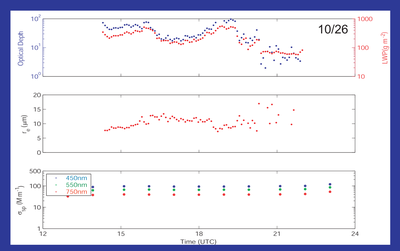
Effective radius can be determined by slope of plot of τ vs. LWP.



- Scatterplots of optical depth against LWP show wide variation on selected days.
- The wide variation in both is an inherent property of clouds.
- τ exhibited a roughly linear dependence on LWP (Schwartz et al., *PNAS*, 2002) with slopes that varied from day to day.

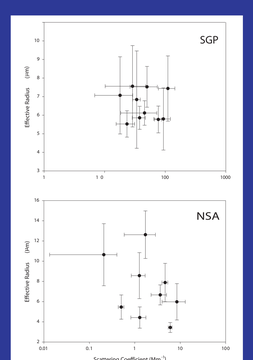
Testing for Aerosol Influence on Cloud Drop Effective Radius



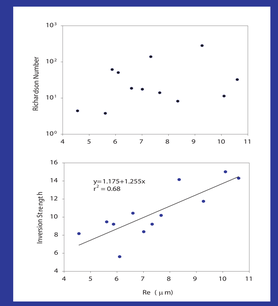


- τ and LWP exhibited similar fluctuation, as expected.
- On 13 Apr at 15UTC, τ and LWP increased substantially, but r_e remained unchanged.
- On 26 Oct at 15-18 UTC, r_e increased from 8-9μm to 12-13μm but aerosol scattering coefficient σ_{sp} remained relatively constant

- Scatterplot of σ_{sp} vs. r_e for the entire data set showed little indication of correlation.
- σ_{sp} at NSA (0.5-8.4Mm^{-1}) lower than at SGP (17.9-110.8 Mm^{-1}) showed wide variations, but exhibited slight negative correlation with r_e.



Meteorological Forcing on Effective Radius



- Meteorological forcings
  - Richardson number (Ri) : buoyancy term vs. turbulence
  - Inversion strength : stability above the Mixed Layer (ML)
  - ML height, ML potential temperature, etc.
- Only inversion strength could be weakly correlated ($r^2 = 0.68$) with r_e.

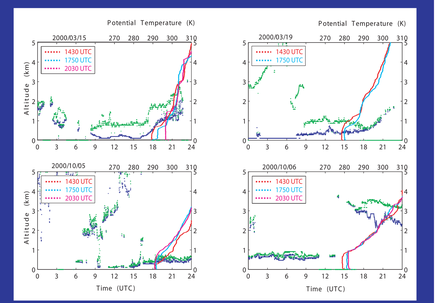
  Stronger stability associated with larger r_e.
  - Stability possibly suppressing the updraft, less supersaturation, and fewer cloud drops
  - Moisture exchange in association with vertical entrainment

Richardson Number $Ri = \frac{g}{\theta_l}\frac{\frac{d\theta_{zi}}{dz}}{\left(\frac{du_{zi}}{dz}\right)^2}$

Inversion Strength $\Delta\theta = \theta^{1km}_{TML}$

Vertical Decoupling

If cloud layer existed above the ML such as 03/15 and 10/06, the aerosol property at the surface may be different from that of the cloud layer. It could decrease correlation of aerosol and cloud drop radius



Summary and Future Work

- τ exhibited a roughly linear dependence on LWP, indicating fairly constant r_e on any given day.
- r_e varied significantly from day to day.
- No significant evidence of aerosol influence on r_e.
- Results suggest stability could be a controlling factor on r_e, and supporting analyses for stability influence is needed.
- Correction of LWP is required for clouds perturbed by drizzle.

Acknowledgment

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